A Genetic Approach to Transmission Rate and Power Control for Cellular Mobile Network (ICEIC'04)

Lee YoungDae* and Park SangBong*
* Dept of Information and Communication, Semyung University, Jechon City, 390-711, Korea
Tel : +82-043-649-1416 Fax : +82-043-649- 1278 E -mail: youngdae77@yahoo.co.kr

Abstract: When providing flexible data transmission for future CDMA(Code Division Multiple Access) cellular networks, problems arise in two aspects: transmission rate. This paper has proposed an approach to maximize the cellular network capacity by combining the genetic transmission rate allocation and a rapid power control algorithm. We present a genetic chromosome representation to express call drop numbers and transmission rate to control mobile's transmission power levels while handling their flexible transmission rates. We suggest a rapid power control algorithm, which is based on optimal control theory and Steffenson acceleration technique comparing with the existing algorithms. Computer simulation results showed effectiveness and efficiency of the proposed algorithm Conclusively, our proposed scheme showed high potential for increasing the cellular network capacity and it can be the fundamental basis of future research.

1. INTRODUCTION

Various information services such as file and image service including voice, email transmission are needed for future cellular networks. In order to support these services with various rate and quality of service, efficient use of the available wireless resource is essential. DS-CDMA system is one of the leading standards because of its advantages in system capacity and flexible to support variable data rate services. Data rate transmission adjustment provides the possibility for efficient usage of radio resources.

In CDMA mobile networks, transmit power control is needed to provide each user an acceptable connection by limiting the interference seen by other users. Effectively centralized or distributed power control is essential and important for high capacity cellular radio networks. In recent, many researchers have investigated a variety of power control algorithms from a different point of view.

In fact, the rate transmission control and power control are closely related each other in practice. Most of all conventional power control methods, however, deal only with fixed data rate during the power control process and has focused on finding a power assignment that maximizes the minimum carrier-to-interference ratio and transmission rate of each user, which is known and fixed. Moreover, their works on this topic have inherent limitation by assuming that CIR(Carrier to Interference Ratio) and transmission rate are continuous functions.

However, it should be emphasized here that the transmission rate is not continues but it is distinct in practice such as DS-CDMA and EDGE(Enhanced Data rates GSM Evolution) cellular system. For these reasons, it is not so easy to develop efficient data rate control in CDMA due to maximum transmit power control constraints and the researches combining them are believed to yet immature in spite of its importance. In a power control process, when all over-allocation occurs in some channel and not all transmitters can be supported, some of them have to be removed. Transmitter removal is a kind of NP-complete problem.

In this work, we propose a novel GA(Genetic Algorithm) based scheme for combining power control and data rate transmission adjustment considering removal to increase cellular network capacity. The formulated problem to solve belongs to a kind of NP hard problem, which implies that any well-known exact algorithm will run exponentially in time as the size of problem instance grows. Moreover the design parameters contain mixed variables such as distinct variables including continuous real ones.

The main idea of the proposed scheme is divided into two parts: The first one is in applying GA to the distinct variables such as multi rate data transmission and call drop. The binary genetic representation is believed to be very effective in these variables. The second one is in utilizing our previously suggested power controller. Our power control algorithm has very rapid convergent rate comparing with the representative distributed power controller suggested by others. The remainder of the paper is organized follows. In section 2, we introduce the system model. We suggest the rapid power control method in section 3 and present a genetic solution procedure in section 4. Simulation experiment is discussed in section 5. We finally conclude our remarks in section 6.

2. SYSTEM DESCRITON

2.1. System Model

Consider an uplink of a cellular CDMA system, in which N mobiles are active in the system. We consider that stationary link gain between a base station i and a mobile j, and it is given by g_{ij} Fig .1 shows an illustration of link gains.

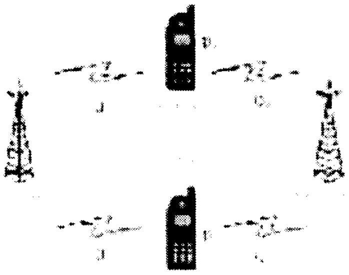


Fig.1 illustration of link gains

Without loss of generality, we will assume that mobile *i* is communicating with base station *i*. In a CDMA system, many mobiles will communicate with the same base station through the same frequency channel. Thus, in our notation, base station *i* and *j* may denote the same physical one if the mobile *i* and *j* are assigned to the same base station. The current SIR $\gamma_i(k)$ at the base *i* is given by

$$\gamma(k) = \frac{q_i(k)}{I_i(k)} = \frac{W}{R_i}\frac{g_{ii}p_i(k)}{\sum_{j=1,j\neq i}^{N} g_{ij}p_j(k) + \nu_i}, \qquad i = 1,2,\Lambda\ ,N \tag{1}$$

In the above, *k* denotes an instant time, $q_i(k)$ in the numerator part is the power received from transmitter *i* at receiver *i* and $I_i(k)$ in the denominator part is the received interference plus noise power at receiver *i*. The quantity ν_i is thermal noise variance at receiver *i*. R_i is the transmitted from the mobile and W is the total spread spectrum bandwidth occupied by CDMA.

For the instant time *k*, let us assume that each mobile should achieve the target SIR γ_i^t as follows.

$$\gamma(k) \geq \gamma_i^t, \qquad i = 1,2,\Lambda\ ,N \tag{2}$$

2.2. Transmission Rate

If a nonnegative power vector ***p*** is within the maximum criterion Eq.(11) as well as the signal quality requirement Eq.(12), it is called effective. Let E be the set of all effective power vectors for the considered system, then the shape of E typically depends on transmission bit rate $R = \{R_1, R_2, \Lambda\ R_N\}$. If effective power is nonzero, then the corresponding *R* is called admissible to the system.

On the contrary, every power control converges to an effective power if the given (fixed) transmission is admissible. In practical systems, the feasible transmission modes are often discrete and finite; the number of link adaptation schemes, code rates and processing gains. Therefore, we consider here that each user can choose transmission out of *K* possible rates such that $R_i \in \{r_i^1, r_i^2, \Lambda\ r_i^K\}$.

2.2. Transmitter Removal

In a power control process, when all over-allocation situation occurs in some channel and not all transmitters can be supported, then some of them have to be removed. Transmitter removal is a kind of NP-complete problem. There may be one-by-one removal or multiple removal method and these removal methods can be or cannot be combined with power control.

Outage probability measures the expected proportion of mobiles, which have to be removed by a removal algorithm. Recently, a family of centralized single transmitter removal algorithm has bee proposed. Among those, SMIRA is the algorithm considering the smallest outage probability, which computes the largest eigenvalue of the gain matrix like Eq.(8). Thus, it can determine whether or not all transmitters can be supported. However, in practice, it is desirable that removal algorithms must be distributed, and mainly based on local measurement.

2.4. The Ordinary Power Control

Let us define a *N* by *N* matrix $H = [h_{ij}]$ such that

$$h_{ij} = \begin{cases} \dfrac{\gamma^t g_{ij}}{g_{ij}}, & for \quad i \neq j \\ 0, & for \quad i = j \end{cases} \tag{3}$$

Additionally, let us define a vector $b = [b_i]$ such that

$$b_i = \frac{\gamma^t \sigma_i^2}{g_{ii}} \tag{4}$$

Converting Eq.(1) into a matrix form, we have the following linear algebraic equations of power control problem.

$$Ap = b \tag{5}$$

Where, $A = I - H$ and $p = [p_i]$ denotes the power vector.

In the literature [5], a necessary condition is derived to achieve feasible power for link gain matrix $G = [g_{ij}]$.

$$\gamma_i^t \gamma_j^t \leq \frac{g_{ii}g_{jj}}{g_{ij}g_{ji}} \tag{6}$$

Similarly, maximum achievable SIR is derived in [4]. Let $\bar{\lambda}$ be the largest real eigenvalue of the following matrix

$$Z = \begin{cases} \dfrac{g_{ii}}{g_{ij}} & i \neq j \\ 0 & i = j \end{cases} \tag{7}$$

Then, the maximal achievable eigenvalue of matrix *Z* is given by

$$\bar{\gamma} = \frac{1}{\bar{\lambda} - 1} \tag{8}$$

and the power vector p^* becomes the corresponding eigenvector.

A suitable power control algorithm should converge to the solutions in a quick and distributive way, while feasible system should support as many users possible. It was suggested that Eq.(4) be solved using the Jacobi fixed-point iterations [6], which leads to the following algorithm.

$$p_i(k+1) = (I - A)p_i(k) + b \tag{9}$$

$$p_i(k+1) = \frac{\gamma^d}{\gamma_i(k)} p_i(k) \tag{10}$$

where, SIR $\gamma_i(k)$ is given like in Eq.(1) at the base *i*. A nice feature of the algorithm in Eq.(10), which is called DPC(Distributed Power Control) algorithm, is that only the information about the current mobile power and the current SIR is sufficient to update the mobile power.

Assuming that the transmitted powers are constrained to

$$0 \leq p_i(k) \leq p_i^U \tag{11}$$

where, p_i^U describes the maximum mobile power. Then, algorithm Eq.(10) appropriately modified into the following DCPC(Distributed Constrained Power Control) algorithm [7].

$$p_i(k+1) = \min\left(\frac{\gamma^t}{\gamma_i(k)} p_i(k),\ p_i^U\right) \qquad (12)$$

The DCPC provides a theoretical background of IS-95 and W-CDMA power control. Furthermore, it has also been much employed for simulators of cellular wireless system and it is often used as a building block of removal algorithms aiming at reducing the co-channel interference, hence maximizing bandwidth utilization.

Convergence properties of this algorithm were studied in [7][8]]. Since this method is based upon a fixed-point algorithm, it usually has slow convergence to the sought solution. Note that the fixed-point algorithms, in general have the linear rate of convergence.

3. THE SUGGESTED POWER CONTROL

3.1. Optimal Control

In this section, we present a rapid distributed power superior to the well-known ordinary DCPC.

The preliminary step for the proposed scheme is to make the transmission power proportional to the error between the actual SIR and the desired SIR. Define the transmission power change from time step *k* to *k+1* as

$$\Delta p_i(k+1) = p_i(k+1) - p_i(k) \qquad (13)$$

Let the error between the actual SIR $\gamma_i(k)$ and the desired SIR γ_i^t be noted by $e_i(k)$ for each mobile *i* at the *k*-th time instant,

$$e_i(k) = \gamma_i^t - \gamma_i(k) \qquad (14)$$

We consider the following control algorithm

$$\Delta p_i(k+1) = \alpha_i(k) e_i(k)$$

or $p_i(k+1) = p_i(k) + \alpha_i(k)(\gamma_i^t - \gamma_i(k))$ (15)

where, $\alpha_i(k)$ is the control gain to be determined through the optimization procedure, in which the square norm of the error is minimized. The first stage of our scheme is to find the optimal control gain $\alpha_i(k)$ such that minimize the cost

$$J_i(k) = e_i(k+1)^2 \geq 0 \qquad (16)$$

To solve this problem, let us denote the channel variation

$$\beta_i(k) = \frac{g_{ii}}{I_i(k)} = \frac{\gamma_i^t(k)}{p_i(k)} \qquad (17)$$

, and the control gain as

$$\alpha_i(k) = \begin{cases} \dfrac{1}{\beta_i(k)}\left(1 - \dfrac{\gamma_i^t}{e_i(k)}\right) + \dfrac{1}{\beta_i(k+1)} \dfrac{\gamma_i^t}{e_i(k)} & \text{if } e_i(k) \neq 0 \\ 0 & \text{if } e_i(k) = 0 \end{cases} \qquad (18)$$

This is the optimal, because the partial derivative of the cost $J_i(k)$ over the gain $\alpha_i(k)$ is zero.

$$\frac{\partial J_i(k)}{\partial \alpha_i(k)} = \frac{\partial (e_i(k+1)^2)}{\partial \alpha_i(k)} = 0 \qquad (19)$$

Furthermore, the quadratic cost function of error is semi-definitely positive as it can be seen in Eq.(16). Because a mobile terminal has limitations in instantaneous power transmission, it is needed to find the optimal gain considering the constraints in Eq.(11), which minimizes the cost $J_i(k)$.

The solution of this nonlinear programming problem is given by

$$p_i(k+1) = \begin{cases} p_i^L & \text{if } \beta_i(k+1)\ \phi\ \dfrac{\gamma_i^t}{p_i^L} \\ p_i^U & \text{if } \beta_i(k+1)\ \pi\ \dfrac{\gamma_i^t}{p_i^U} \\ p_i(k) + \alpha_i(k) e_i(k) & \text{otherwise} \end{cases} \qquad (20)$$

The detailed derivation of the results in Eq.(20) can be obtained by using the well-known Kuhn-Tucker conditions [9], which can be found in [10]. It should be reminded that an estimator or a predictor is needed in order to compute $\alpha_i(k)$. In this paper, we simply employed the typical DPC in Eq.(10) to make one-step prediction of the channel variation.

In numerical analysis, a variety of acceleration techniques exist to speed up the convergence of fixed-point algorithms. Among these, Steffensen method produces the quadratic convergent rate for the corresponding fixed-point algorithm. In the following, under the assumption that the current SIRs are known ($\gamma_i(k)$ for each *k*-th instant), we derive the accelerated version of the Scheme 1 using the Steffensen method. In that direction, we present the Steffensen method and then apply it to our scheme 1 for DPC.

3.2. Proposed Rapid Power Control (RPC)

The overall of the proposed Rapid Power Control(RPC) algorithm can be described as the following two schemes.

[RPC Algorithm]

Scheme 1

Step 1-1: With the given power vector ***p*** and with the achievable target SIR γ_i^t, calculate the current instant SIR $\gamma_i(k)$ with Eq.(1), the current channel variation $\beta_i(k)$ with Eq.(17) and the SIR error $e_i(k)$ with Eq.(14), respectively.

Step 1-2: Predict the next instant mobile power $p_i(k+1)$ by Eq.(10), the next instant SIR $\gamma_i(k+1)$ by Eq.(1), the next instant channel variation $\beta_i(k+1)$ with Eq.(17), respectively.

Step 1-3: Compute the control gain $\alpha_i(k)$ using Eq.(18).

Step 1-4: Modify the next instant power $p_i(k+1)$ using Eq.(15) and Eq.(20).

Step 1-5: If $\sum_{i=1}^{N} |e_i(k)| / N \leq \varepsilon$ for $k \geq 1$, where ε is a desired tolerance, then stop since the result is obtained. Otherwise, increase *k* by 1 and go to Step 1.

Scheme 2

Step 2-1: During the process of Scheme 1, if *k* equals to 2, and mobile powers $p_i(0), p_i(1)$ and $p_i(2)$ are obtained, then escape from the above loop procedure. That is, two initial iterations are performed. After then, perform the following Steffensen iterations.

Step 2-2: Set $p_i^s(0) = p_i^s(0), p_i^s(1) = p_i^s(1)$ and $p_i^s(2) = p_i^s(2)$

Step 2-3: Calculate

$$p_i^s(k) = p_i^s(0) - \frac{\left(p_i^s(1) - p_i^s(0)\right)^2}{p_i^s(2) - 2p_i^s(1) + p_i^s(0)}, \qquad k = 1, 2, \Lambda \qquad (22)$$

Step 2-4: Evaluate the current instant SIR $\gamma_i(k)$ and the error $e_i(k)$ employing $p_i^s(k)$ with the current instant power $p_i(k)$.

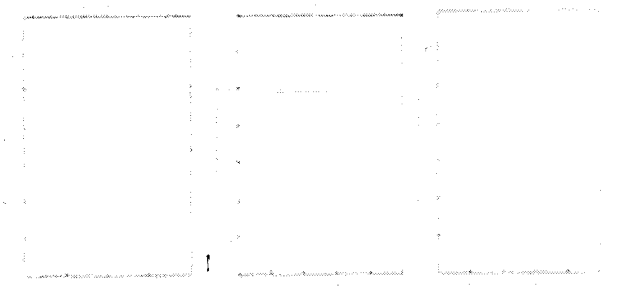
Step 2-5: The same like Step 1-5.

It should be emphasized here, only two iterations of Scheme 1 are used to initiate Steffensen iterations of Scheme 2 and Steffensen iterations run until the completion.

3.3. RPC Performance

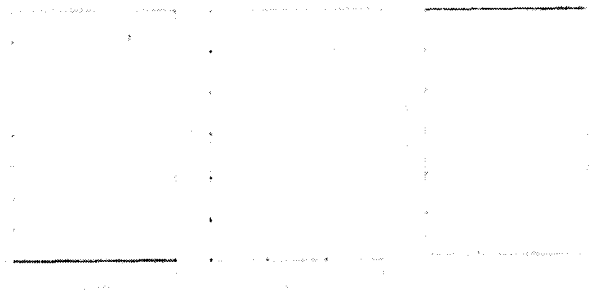
To show performance of the proposed RPC here, we solved a simple numerical example for $N = 2$ using data taken from Jantti and Kim [12]. The link gains are given by $g_{11} = 0.3268$, $g_{12} = 0.0534$, $g_{21} = 0.0602$, $g_{22} = 0.3836$ and the receiver noise is set to $\nu = 0.1$. The target SIR is assumed to be identical for both user data and equal to 6 dB(3.981 in absolute values). The initial mobile powers are given by $p_1(0) = 1$ and $p_2(0) = 2$. Fig.2 and Fig.3 show that our proposed schemes have rapid convergence over the ordinary DPC scheme using Jacobi iterations.

Furthermore, it is observed in Fig.3 (b) and (c) that Scheme 2 with Steffenson acceleration, is faster than Scheme 1. The proposed schemes show almost straight line of search pattern unlike zigzag search pattern of the ordinary DPC, which can be observed in Fig.2. Thus, the proposed RPC scheme has a strong point over the ordinary DPC in convergence rate and search property.



(a) Typical DPC (b) Scheme 1 (c) Scheme 2

Fig.2 Mobile users' SIRs per iterations



(a) Typical DPC (b) Scheme 1 (c) Scheme 2

Fig.3 Comparison of power controls

4. GA ASSISTED SOLUTION

4.1. Genetic Algorithm

GA(Genetic Algorithm) is an adaptive procedure that finds solutions to problems by genetic process based on natural selection. They are iterative search algorithms with various applications. Genetic scheme not only combines survival of the fittest, genetic operations, random but structured searches but also performs parallel evaluation of solutions in the search space. GA has been well applied to a variety of problems such as NP-hard problems and mixed integer problems[13][14].

In this work, a transmission rate value and call-drop consists of an individual as a potential solution for the adjustment problem. In order to represent a transmission rate level value and to determine the call or drop of a user, we transform transmission rate and removal into binary numbers or strings which can inherently satisfy the discrete constraint condition.

4.2. Chromosome and Fitness

We design a chrome C_i of a user i bits such that $C_i = b_0 b_1 b_2 \Lambda\, b_L$,. Here, b_0 is a bit representing admission of a call or a removal for user *i*. If it is 1, then a call is admitted. Otherwise, if it is 0, the call is dropped or removed. Where, $b_1 b_2 \Lambda\, b_L$ is binary coding of an instant transmission rate R_i of user i with L bits. Then, the chromosome of a population or a string is described as $C = C_1 C_2 \Lambda\, C_N$.

Thus, the bits of transmission rate and a bit of call admission for each mobile terminal constitute one chromosome. Therefore, if the number of mobiles is *M*, there are *M* groups of population. The evaluation function of GA determines the fitness of potential solutions. The following evaluation function is used in order to support systems as many mobiles as possible as follows.

$Fit = \max S$

where, S is the number of supported mobiles satisfying the SIR threshold constraints. In other words, it is the number of mobiles of which call is admitted or the first bit b_0 is 1

4.3. The Overall Procedure

The overall procedure of the proposed algorithm is as follows.

Step 0(Initialization): Start with complete set of active mobile *N*., an initial power vector *p(0)*, and initial transmission rate vector *r(0)*. Set the parameters of GA.

Step 1(Termination Criteria): For every mobiles do Steps 2-4 until any predefined conditions is satisfied.

Step 2(Evaluation): Calculate the fitness of the population. Keep the elite chromosome.

Step 3(Evolution): Evolve the population by manipulating chromosomes using GA operations. Set n=n+1 and go to Step 2.

5. SIMULATION

The main purpose of the experiments is to investigate how much system capacity can be increased and how much extra effort is needed in combining power control and multi rate adjustment. Through computational experiments, we will show that the proposed scheme outperforms some those of existing schemes. The DS-CDMA system with 19 omni BSs located in the center of 19 hexagonal cells is used as a test system like as Fig.4.

We here consider IS-95 example, where spreading bandwidth is 1,2288MHz. Data rate can one value of IS-95 rate set such as 1200,1800,2400,4800,7200,9600,14400 bps per each mobile. For instance, 95 mobiles are generated, locations of which are uniformly distributed over 19 hexagonal cells. The initial power for each mobile is randomly chosen from the interval [0,1].

The link gain $g_{ij} = s_{ij} \cdot d_{ij}^{-4}$, where s_{ij} is the log normally distributed shadowing factor is generated according to a expectation value of 0dB and a standard value of 6dB. d_{ij} is the distance of base i and mobile j. The base station receiver noise is taken to be 10^{-15}. The relative maximum mobile terminal power is set to 1. The target SIR(Signal to Noise Ratio) is set to 7.2dB.

We selected population size of GA as 100, crossover rate as 0.8, mutation rate as 0.1, termination criteria as 200 generations and like etc. Fig.5 shows an input screen of GA parameters. Failure rate, power consumption, supportable rate are investigated.

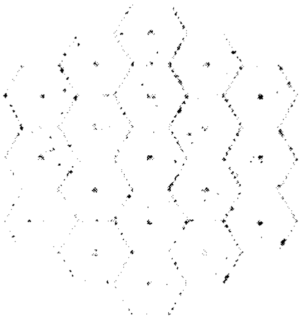


Fig.4 Simulated system

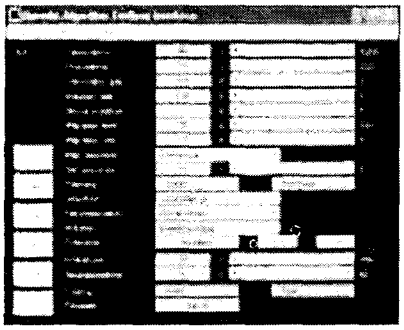


Fig.5 GA parameters input screen

Each simulation has been repeated 100 times and then the average value is reported. According to the results, the power levels and supportable rate outperform the ordinary algorithm. Thus, the results showed that our proposed scheme significantly enhances optimization and calculation speed while satisfying the given constrains.

6. CONCLUSION

We firstly formulated a GA assisted optimization problem to improve the CDMA network capacity. The target is to maximize the number of supported mobiles by adjusting data transmission in conjunction with local power control satisfying the given CIR threshold. It results in a kind of NP hard problems, which have the mixed design parameters to search consisting of distinct variables including continuous real ones.

Secondly, to solve the problem, we presented a genetic scheme to adjust data transmission and call/drop combined with power control The binary GA based coding scheme cannot only represent the distinct variables such as call/drop and data transmission but it can also deal with the NP hard natured problem efficiently.

Finally, our rapid power controller can reduce the computation time comparing with the existing distributed power controllers. It is not only based theoretically on the optimal power control but also it employs the advantage of Steffensen iteration to accelerate the search.

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